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ORIGINAL ARTICLE

The Role of Ultrasonography in Dermatology

Ana M. Roșca[1], Sorin A. Coman[2,3], Andrei C. Costache[3], Daniel O. Costache[1,4]

[1] Dermatology Clinic, Dr. Carol Davila Central Military Emergency University Hospital, Bucharest, Romania; anaa.rosca@gmail.com (AMR)
[2] Elias University Emergency Hospital, Gastroenterology Service, Bucharest, Romania
[3] Carol Davila University of Medicine and Pharmacy, Bucharest, Romania
[4] II Dermatology Discipline, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania; daniel.costache@umfcd.ro (DOC)

Correspondence: Sorin A. Coman, sorin.coman95@gmail.com

Abstract: Ultrasonography (US) is one of the most widely utilized imaging methods in contemporary medical practice. Unlike other imaging techniques primarily within the radiology domain, ultrasonography has been adopted by various medical and surgical specialties and tailored to the specific needs of each. This adaptability has contributed to ultrasonography's rapid diversification and remarkable evolution over recent decades. Ultrasonography was first employed in dermatology in 1979 when Alexander et al. used it to measure skin thickness. However, due to the limitations of conventional ultrasound devices at the time, which had resolutions and frequencies below 15 MHz, detailed elements of the skin could not be analyzed, tempering enthusiasm for the technique [2]. Modern dermatologic ultrasonography began with the development of fixed-frequency devices operating above 20 MHz, enabling detailed visualization of skin structures. Numerous studies on skin physiology and pathophysiology were conducted using this approach. Modern ultrasonography enables us to visualize skin structures, at times surpassing the detail provided by traditional anatomical dissections in educational settings. Given that patient safety and quality medical care remain fundamental priorities, ultrasonography, with its safety profile and versatility, represents the next step in modern dermatology. Ultrasonography represents a rapidly evolving diagnostic tool that holds the promise of significantly improving diagnostic accuracy and the quality of medical dermatology practice.

Keywords: skin, ultrasonography, high frequency

HISTORY

Ultrasonography (US) is one of the most widely utilized paraclinical methods in contemporary medical practice. Unlike other imaging techniques primarily within the radiology domain, ultrasonography has been adopted by various medical and surgical specialties and tailored to the specific needs of each. This adaptability has contributed to ultrasonography's rapid diversification and remarkable evolution over recent decades.

In its early days, the first ultrasound devices were massive machines requiring dedicated rooms, with images generated in A-mode (the earliest form of ultrasound imaging) as simple linear traces. Today, we use miniature devices, including wireless probes that connect to smartphones or tablets, delivering high-resolution images. Furthermore, numerous new ultrasound modalities have emerged, such as Doppler, pulsed Doppler, e-flow, power Doppler, and harmonic mode for contrast-enhanced ultrasonography. Simultaneously, many probes are available: linear, convex, cardiac, intraoperative, and hockey stick probes, among others [1–3].

Ultrasonography was first employed in dermatology in 1979 when Alexander et al. used it to measure skin thickness. However, due to the limitations of conventional ultrasound devices at the time, which had resolutions and frequencies below 15 MHz, detailed elements of the skin could not be analyzed, tempering enthusiasm for the technique [2].

Modern dermatologic ultrasonography began with the development of fixed-frequency devices operating above 20 MHz, enabling detailed visualization of skin structures. Numerous studies on skin physiology and pathophysiology were conducted using this approach. However, fixed-frequency devices had limited penetration depth and lacked capabilities such as color Doppler. Additionally, skin thickness varies based on anatomical location and pathology. For instance, the dermis on the dorsal trunk can reach up to 43 mm, which can hinder the detection of deeper lesions using fixed-frequency probes [2,3].

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Modern ultrasonography equipment with variable frequencies exceeding 15–22 MHz was developed to address these challenges. These devices offer features such as power Doppler, color Doppler, and small, easy-to-use probes designed for examining complex anatomical regions like nails, the face, or the ears [1].

ULTRASONOGRAPHY OF NORMAL SKIN

Ultrasound imaging of the skin results from the interaction between acoustic waves and the skin's layers, which reflect these waves differently.

Broadly, the epidermis appears as a hyperechoic line due to its high keratin content, while the dermis is less hyperechoic because of its high collagen concentration. The subcutaneous tissue consists of hypoechoic fat lobules separated by hyperechoic collagen septa [4].

Doppler ultrasound, including pulsed and power Doppler, assess vascular patency and organ perfusion. Based on vascular characteristics, it is possible to differentiate benign from malignant lesions [4]. Furthermore, blood supply can be monitored to assess the treatment response and inflammatory pattern. A limitation of Doppler ultrasonography is its reduced sensitivity in detecting blood flow in certain cases [2].

Contrast-enhanced ultrasonography allows visualization of microcirculation and neovascularization, aiding in cases where Doppler sensitivity is low. Parameters such as blood flow distribution, filling dynamics, and flow velocity assist in distinguishing between benign and malignant lesions [2].

Originally developed for evaluating hepatic fibrosis, shear wave elastography has recently shown promise in assessing fibrotic changes across various organs and pathological conditions. Its utility has extended to inflammatory skin diseases, such as hidradenitis suppurativa, as well as connective tissue disorders, where it enables differentiation between active inflammatory stages and chronic fibrotic phases, thereby enhancing diagnostic accuracy and disease staging [2].

Three-dimensional ultrasound, made possible through advanced imaging software, allows for the precise reconstruction of cutaneous structures in three dimensions. This technology provides a detailed visualization of both lateral and deep margins of lesions, enabling accurate mapping of their extent. By offering a comprehensive understanding of the spatial relationship between the lesion and surrounding tissues, it serves as a valuable tool for preoperative planning, ensuring well-defined excision margins and optimizing surgical outcomes [2].

There are two essential requirements for performing cutaneous ultrasonography: a color Doppler ultrasound device with a linear or compact linear probe of variable frequency, operating at ≥15 MHz, and an operator specialized in dermatological pathologies with expertise in ultrasonography [3].

As the emission frequency of an ultrasound probe increases, penetration depth decreases. Therefore, two probes with different frequency ranges may be necessary to visualize both the skin and deeper layers.

The axial spatial resolution of ultrasonography is superior to that of other imaging techniques, such as MRI or CT. For example, a 15 MHz probe has an axial resolution of 100 µm, while a 70 MHz probe has an axial resolution of 30 µm. By comparison, a 3.0 T MRI offers a resolution of 400 µm, and a 7.0 T MRI achieves a resolution of 100 µm. This parameter is crucial for studying the most superficial structures, as detecting small structures such as hair follicles is impossible with MRI or CT.

In addition to technical advantages, ultrasonography is cost-effective compared to MRI or CT, involves no radiation exposure, and can be repeated as frequently as necessary without hesitation or restrictions [3].

Ultrasound examination typically consists of a clinical evaluation followed by grayscale imaging, color or power Doppler ultrasonography, spectral curve analysis of vascular lesions (pulsed Doppler), elastography for detecting fibrosis, and contrast-enhanced ultrasonography for assessing the vascularization of cystic or tumoral formations [3].

CLINICAL APPLICATIONS OF CUTANEOUS ULTRASONOGRAPHY

Grounded in these principles, the clinical applications of this imaging modality have expanded to encompass the differentiation of benign from malignant cutaneous tumors, precise localization and detection of subcutaneous implants, evaluation of traumatic injuries and foreign bodies, and assessment of cutaneous vascular malformations. Furthermore, it plays a critical role in monitoring cutaneous changes in systemic diseases, guiding preoperative planning and intraoperative procedures, assessing treatment response, and reducing complications associated with aesthetic interventions [3].

Doppler ultrasonography is especially valuable for evaluating inflammatory processes, detecting neovascularization, and identifying vascular malformations [4].

Conventional B-mode imaging is employed to evaluate tumor morphology, including lateral and deep margins relative to surrounding tissues (muscle, cartilage, or bone), contours, echogenicity, and structure. Tumor thickness is measured along the axis of greatest depth, from just below the hyperechoic keratin band (epidermis) to the deepest invasion margin. Tumor thickness, particularly the Breslow index in melanomas, is a critical prognostic factor that informs therapeutic strategies. Studies have shown a correlation

between ultrasound depth measurements and the Breslow index, underscoring ultrasonography's utility in preoperative planning and staging of malignancies [4,5].

In addition to delineating tumor structures, ultrasonography (US) provides evidence of their benign or malignant nature using Doppler mode and contrast-enhanced ultrasonography. Vascular findings suggestive of malignancy include hypervascularity, vascular disorganization, and irregular blood flow patterns with peripheral or mixed distribution, increased vascular velocity, and the presence of vascular pedicles. Furthermore, contrast-enhanced ultrasonography assesses tumor vascularization, starting with the arterial phase, followed by the venous phase, maximum blood supply, wash-up time, drainage time, and distribution patterns in the area of interest. According to published data, malignant tumors exhibit a heterogeneous filling pattern during contrast-enhanced ultrasonography, with significantly increased values during the wash-out phase [4,5].

Ultrasound can also be used to evaluate the responses to topical therapies in cases of actinic keratoses and superficial basal cell carcinomas.

In the case of hidradenitis suppurativa, ultrasonography has proven to be highly valuable, providing objective data for disease staging, enabling the calculation of severity scores, and monitoring disease activity with greater accuracy than clinical examination. Recent studies have also demonstrated its utility in therapeutic decision-making by tailoring treatments based on the degree of inflammation and disease activity visualized ultrasonographically, elements that are difficult to assess with the naked eye. Additionally, treatment responses can be more easily evaluated, providing quantifiable arguments for continuing or modifying therapy. Thus, ultrasonographic investigation is strongly oriented toward patient-centered care and improving quality of life.

Abscesses and cysts can be readily evaluated and diagnosed using ultrasonography. Moreover, ultrasonography guides therapeutic decisions by providing detailed imaging that helps determine the most appropriate approach, whether it involves performing drainage procedures or opting for conservative management [1].

Ultrasound evaluation of plantar wart extension and monitoring treatment response in HPV infections may appear trivial but can become a standard approach in selected cases.

Recently, the use of shear wave elastography has proven beneficial in examining patients with systemic sclerosis. In a study involving 59 patients and 104 plaques of morphea, Wortsman et al. demonstrated that ultrasonography has a sensitivity of 100% and a specificity of 98.4% in distinguishing between lesions in the inflammatory phase and those in the sclerotic phase. Subsequent efforts have been made to standardize results for monitoring treatment response [6].

In pediatric dermatology, ultrasonography is used to monitor treatment responses for infantile hemangiomas and vascular malformations in newborns, employing Doppler mode [7].

Evaluating subungual formations and diagnosing their nature is emerging as a valuable application, considering the limited alternatives for visualizing the nail bed and surrounding structures that are not directly observable [4].

The numerous clinical applications of ultrasonography and its ability to provide objective diagnostic information have increasingly captured the attention of dermatologists.

Although histopathological examination remains the gold standard for diagnosis, its invasive nature limits the ability to comprehensively and dynamically examine the skin [3]. Today, with the advancement of non-invasive skin evaluation techniques, we are entering a new era that promotes non-invasive diagnostic and therapeutic methods. For patients who refuse skin biopsy or for pediatric patients, ultrasonography is an accessible, cost-effective, and minimally invasive investigation that can guide diagnosis.

ADVANTAGES OF ULTRASONOGRAPHY IN DERMATOLOGY

Numerous advantages of ultrasonography have been defined in recent years, with the most relevant being:

1. Real-time and Safe Imaging. Ultrasonography can be performed safely at any time, even in children and pregnant women, allowing for repeated imaging to track lesions and vascularization without exposure to ionizing radiation.

2. High Resolution Across Layers. Modern ultrasonographic systems enable the identification of changes across both superficial and deep layers. The equipment also allows the examiner to adjust the depth of imaging depending on the clinical needs.

3. Comprehensive Cutaneous Visualization. Unlike methods such as dermoscopy or optical coherence tomography (OCT), ultrasonography allows examination of cutaneous structures at any depth. For example, dermoscopy provides a maximum penetration depth of 200–250 µm, while OCT reaches 1.5–2 mm. With OCT, structures beyond the penetration depth of light appear blurred or black, limiting its utility in evaluating the deeper margins of tumors.

4. Whole-Skin Examination. Unlike histopathological examination, which is restricted to a single tissue sample, ultrasonography facilitates the examination of the entire skin. This is particularly beneficial for diagnostic support, disease staging, and monitoring inflammatory disease activity.

5. Absence of Radiation Exposure. Ultrasonography uses sound waves, making it a radiation-free and safe imaging modality.

6. Accessibility for Patients with Implants. Unlike MRI, ultrasonography is safe for patients with pacemakers or metal implants.

7. Superior Axial Spatial Resolution. Ultrasonography's spatial resolution surpasses that of CT or MRI, making it an indispensable tool for evaluating fine superficial structures such as hair follicles.

8. Versatile Anatomical Access. Ultrasonographic probes can be applied to any anatomical region, regardless of shape or contour, enabling the visualization of otherwise inaccessible areas [3].

LIMITATIONS OF CURRENT TECHNOLOGY AND PRACTICE

While ultrasonography has significant advantages, it is not without limitations. Lesions smaller than 0.1 mm at 15 MHz or 0.03 mm at 70 MHz remain challenging to visualize. Furthermore, intraepidermal lesions like macules (e.g., lentigines or café-au-lait spots) and melanin are not easily detected [7,8].

Artifact interference, such as shadowing in hyperkeratotic lesions, can also limit diagnostic accuracy. Additionally, the efficacy of the method is heavily dependent on the operator's expertise. Evaluators must have advanced dermatological knowledge and specific ultrasonographic training to interpret findings accurately.

USE OF ULTRASONOGRAPHY IN AESTHETIC MEDICINE

According to statistics from the American Society of Plastic Surgeons, minimally invasive cosmetic procedures have increased by 174% over the past 20 years. Concurrently, there has been a global rise in reported complications following injectable and non-injectable aesthetic procedures.

As a result, there is a growing interest in utilizing high-frequency ultrasound (US) as the first-line imaging modality for assessing patient anatomy in the field of aesthetic medicine. Ultrasound enables a virtual dissection of skin layers, providing detailed visualization of the arterio-venous vascular network and its relationship with surrounding tissues. Additionally, most dermal fillers can be visualized using ultrasonography.

In cases of complications following aesthetic procedures, ultrasonography offers precise information about the nature of the complication, the skin layers involved, and the identification of previously injected fillers or materials. Moreover, it can guide the injection of hyaluronidase or the drainage of fluid collections.

Ultrasound is increasingly becoming an essential tool for managing aesthetic patients by offering high-resolution imaging and the ability to assess any cutaneous region. Furthermore, its global availability adds to its practicality. The literature in this field continues to advance, with a recently published book guiding aesthetic practitioners in this emerging domain [9].

ARTIFICIAL INTELLIGENCE IN CUTANEOUS ULTRASONOGRAPHY

With advancements in ultrasonography technology, it is now possible to obtain increasingly detailed information about the skin. Alongside other non-invasive tools such as dermoscopy, optical coherence tomography (OCT), and confocal microscopy, ultrasonography serves as a critical bridge between clinical examination and histopathological assessment.

Cutaneous ultrasonography remains a relatively new interdisciplinary field with vast potential for development. Despite its late introduction into dermatology, the rapid pace of current technological progress highlights the enormous potential for integrating artificial intelligence (AI) with this modality. The simultaneous development of AI tools and the training of dermatologists can transform AI into a reliable software solution with a high degree of accuracy, minimizing diagnostic errors.

The evolution of ultrasonography in skin exploration may allow dermatology to align with other specialties, as AI-driven advancements are adopted alongside medical personnel training.

TRAINING OPPORTUNITIES IN ULTRASONOGRAPHY

Over the past decade, several books have been published on cutaneous and aesthetic ultrasonography, providing foundational knowledge for practical training. In addition to these resources, the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) and the American Institute of Ultrasound in Medicine (AIUM) have developed specialized training courses for professionals in this field.

In this context, the new dermatology residency curriculum has introduced a module on cutaneous imaging, which holds significant potential for development in the coming years [3].

CONCLUSION

Modern ultrasonography enables us to visualize skin structures, at times surpassing the detail provided by traditional anatomical dissections in educational settings. Given that patient safety and quality medical care remain fundamental priorities, ultrasonography, with its safety profile and versatility, represents the next step in modern dermatology.

As the technique continues to mature, emphasis should be placed on:

• Standardization of techniques to ensure consistent and reliable imaging practices.

• Expanding professional training through residency programs and specialized courses.

• Clear classifications and develop AI integration to enhance diagnostic precision and reduce inter-operator variability

Ultrasonography represents a rapidly evolving diagnostic tool that holds the promise of significantly improving diagnostic accuracy and the quality of medical practice in dermatology.

Conflicts of interest and sources of funding

The authors declare that there are no conflicts of interest, financial or otherwise, related to the materials presented herein. The authors declare no conflicts of interest.

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Authors' contribution

Conceptualization (AMR, SAC); methodology (AMR); software (SAC, ACC); validation (DOC); formal analysis (AMR, SAC, DOC); investigation (AMR, SAC); resources (DOC, ACC); data curation (DOC); writing – original draft preparation (AMR, SAC); writing – review and editing of manuscript (AMR, DOC, ACC); supervision (DOC); project administration (DOC). All authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

Not applicable.

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